The Influence of Reradiation on the Phase Pattern of a Medium Wave Radio Navigation System Antenna

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***Abstract*— The transmitting antenna of a medium wave radio navigation system in the presence of a reradiating object is considered. The change in the phase radiation pattern under variations of the underlying ground surface parameters is analyzed. It is shown that the phase pattern non-uniformity can reach tens of degrees. A distortion compensation method is proposed using a phase pattern calibration that takes into account the influence of surrounding objects and a small calibration antenna that allows tracking of changes in ground parameters.**

Keywords*— *ground-based radio navigation system, medium wave range, transmitting antenna, navigation signals reradiation, phase radiation pattern stability

I. Introduction

Despite the active use of satellite navigation in various spheres of human activity, terrestrial radio navigation systems (RNS) continue to play a significant role in radio navigation, due to their high jam immunity compared to global navigation satellite systems (GNSS) [1]. Thus, according to the Rules for the Equipment of Marine Vessels [2] in the Russian Federation, it is a mandatory requirement to use combined signal reception channels operating both on GNSS signals and on ground-based RNS signals. The required positioning accuracy is about several meters or even less in some applications. The base stations of the ground-based RNS radiate a navigation signal in the medium waves range. Usually, the base station transmitting antenna is a vertical monopole equipped with a radial ground screen. RNS user receives the radiated signal of the reference station and retrieves the delay and phase of the signal for further calculation of its coordinates. For accurate coordinates determination, it is critically important that the phase pattern of the reference station antenna has the shape of pure circle and remains stable throughout the entire operating time of the RNS. However, in practice antenna is affected by at least two external factors:

1. Changes in the relative permittivity ε and the conductivity σ of the underlying ground surface at the antenna installation site, depending on weather conditions and time of year.

2. The presence of conductive objects of sufficient height in the vicinity of the antenna, reradiating a navigation radio signal.

It was shown that the combined effect of these factors leads to a significant distortion of the amplitude and phase radiation patterns [3–7]. In some cases, the phase pattern non-uniformity can be tens of degrees, depending on the shape, height of the reradiating object and the distance to it [8]. For example, a phase error as low as 10° will result in a pseudorange error of approximately λ/36, which is 4.4 meters at a frequency of 1.9 MHz. Such error levels are unacceptable in many situations. In a real situation, it is very difficult, if even possible, to choose the placement of the RNS transmitting antenna far enough from the reradiating objects.

Therefore, in order to minimize impact on the accuracy of the RNS, it is proposed to perform a phase pattern calibration procedure. This measurement is supposed to be performed after the base station deployment and taking into account the influence of all surrounding objects. The measured data of the calibration pattern are loaded into the RNS user receiver. Further, when the RNS receiver is functioning, it obtains azimuth of the carrier from other sources (compass or other inertial navigation equipment). Knowing the azimuth, it is possible to determine the direction to the base station and take into account the corresponding correction from the calibration pattern.

II. Modeling

Let's consider an electrodynamic model of a transmitting antenna in the presence of a reradiating object (Fig. 1).

The antenna is a vertical 22 m height monopole with a radial grounding screen and supporting guys. It is located at the coordinate system origin and operates in the medium frequency range as a transmitting antenna. At a distance R from the transmitting antenna, a reradiating object is located. It is a vertical rod with a height of h. The lower end of the

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rod touches the ground surface. Next, we will analyze the phase pattern of such a system in various environmental conditions. Four options of the reradiating rod location are used for consideration: R = 100 m and 200 m, h = 40 m and 80 m.

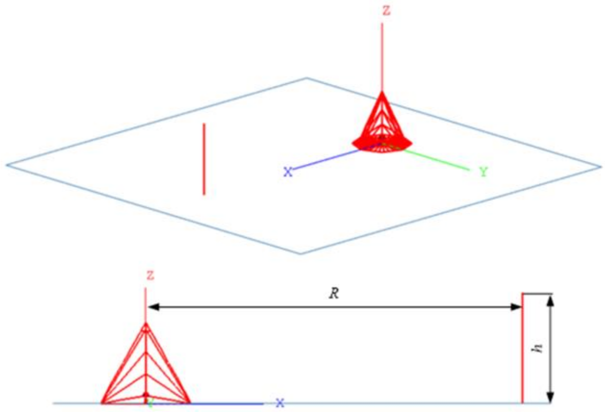

Fig. 1. A model of a transmitting antenna in the presence of a reradiator

Both antenna and reradiator are placed on the flat ground surface with specified permittivity ε and conductivity σ. Using simulation, the results were obtained for "dry" (ε = 4, σ = 0.001 Cm/m) and "wet" (ε = 20, σ = 0.01 Cm/m) underlying ground. Further, the data for the "dry ground" are denoted as DG, "wet ground" − WG. Azimuthal phase radiation patterns Φ(φ) at the frequency of 1.9 MHz have been calculated, then phase pattern non-uniformity is evaluated as ΔΦ = max(ϕ(φ)) – min(ϕ(φ)) within the azimuthal sector φ = 0...360°.

Fig. 2 shows the phase pattern ΔΦ non-uniformity for two ground types depending on the rod height h located at distances R = 100 and 200 m from the antenna of the base station. It is clearly noticeable that the greatest distortions in the pattern are caused by an object with a height close to half the wavelength: λ/2 = 79 m. For objects of a different shape, the "resonant" height will be different [8]. Obviously, when the reradiator is moved away from the antenna, the non-uniformity decreases.

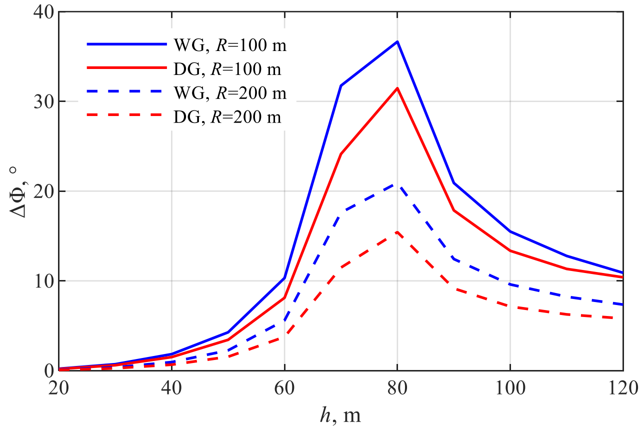

Fig. 2. Phase pattern non-uniformity depending on the height of the reradiating object

Next, it is necessary to consider the change in the azimuthal phase pattern shape when changing the underlying ground surface parameters. Fig. 3, 4 show the azimuthal pattern Φ(φ) for two types of ground at a reradiator distance of 100 and 200 m.

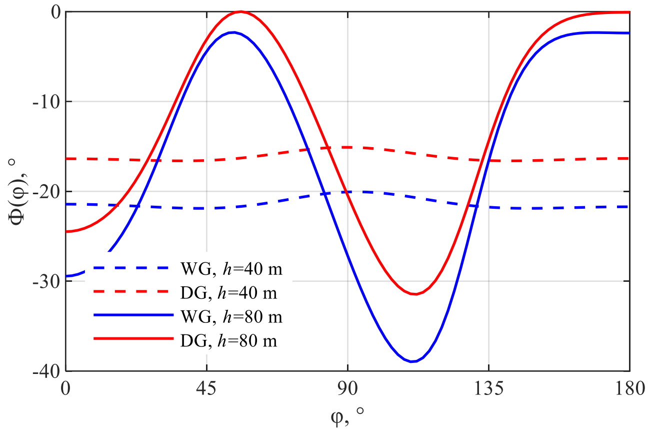

Fig. 3. Phase pattern of the transmitting antenna in the presence of a reradiating object, distance R = 100 m.

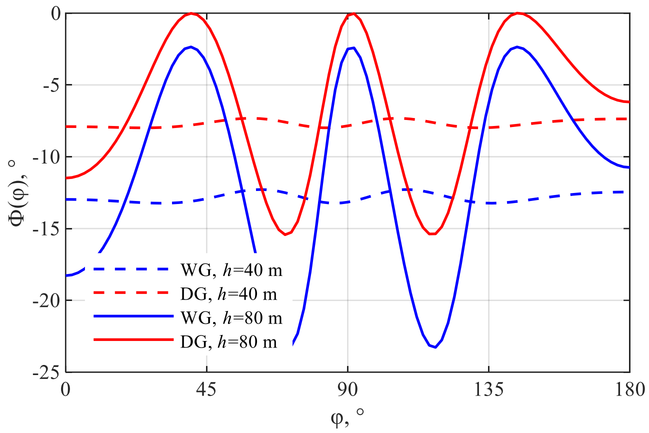

Fig. 4. Phase pattern of the transmitting antenna in the presence of a reradiating object, distance R = 200 m.

As can be seen from the figures, for all the considered rod location options, there is a change in the phase pattern depending on the parameters of the underlying ground surface. The main of interest is the magnitude of this change, which can be expressed as follows:

$$\delta\Phi(\varphi) = \Phi_{WG}(\varphi) - \Phi_{DG}(\varphi),$$

where $\Phi_{WG}(\varphi)$ and $\Phi_{DG}(\varphi)$ are pattern for wet and dry ground, respectively, determined at the same frequency without normalization. When using a calibration pattern, it will be measured once in the operating frequency range for certain ground parameters taking place at that time. Then, when the RNS base station is functioning, the ground parameters will change depending on weather conditions and the time of year. The use of a calibration pattern will be reasonable if the condition $\Delta\Phi > \max|\delta\Phi(\phi)|$ is fulfilled, or

$$\Delta\Phi \,/\, \max|\delta\Phi(\varphi)| > 1. \qquad (1)$$

That is, the phase pattern changes with variations in the ground parameters should be significantly less than the non-uniformity with fixed ground parameters. Otherwise, it will not be possible to eliminate the influence of the azimuthal non-uniformity by means of a calibration pattern. Figure 5 shows the phase pattern change δΦ(φ) calculated with the same rod location options.

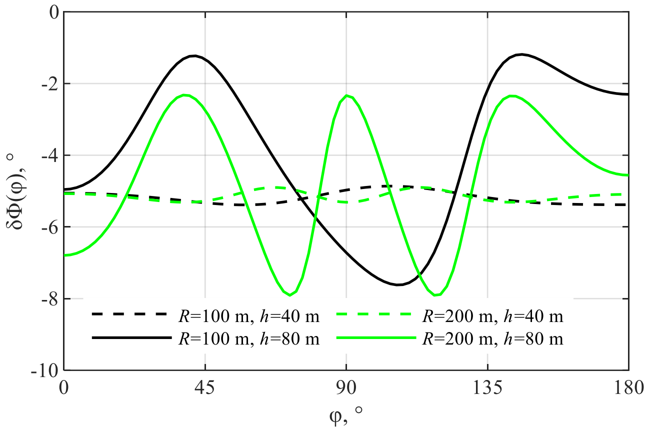

Fig. 5. Phase pattern change with variation of the underlying ground surface parameters

Table 1 summarizes the phase pattern non-uniformity for wet ground $\Delta\Phi_{WG}$, the maximum phase pattern change max|δΦ(φ)|, and the ratio of these two values.

TABLE I.

***R*, m**	***h*, m**	**$\Delta\Phi_{WG}$, °**	**max |δΦ(φ)|, °**	**$\Delta\Phi_{WG}$ / max δΦ(φ)**
100	40	1.8	5.4	0.33
200	40	0.9	5.3	0.17
100	80	36.6	7.6	4.81
200	80	20.9	7.9	2.64

As can be seen from the table, condition (1) is fulfilled only for rod height of h = 80 m. Therefore, the use of a calibration patten is suitable only in cases where the environment of the base station antenna causes a significant (tens of degrees) distortion in the phase pattern shape. For other cases, the phase pattern non-uniformity is comparable and even less than the pattern changes with variations in the ground parameters. In these conditions, the use of a calibration pattern can only have an effect in combination with constant phase correction using a calibration antenna.

A relatively small receiving antenna (field probe, monitor) can be placed at a distance from several hundred meters to few kilometers from transmitting antenna. Monitor receiver should be synchronized with transmitter by means of GNSS, or fiber optic synchronization system. This would allow real time correction of transmitted signal delay and phase variations due to ground parameter changes.

III. Conclusion

By modeling, it was shown that the presence of reradiating objects near the RNS transmitting antenna can lead to significant distortion in the phase radiation pattern and the appearance of non-uniformity of up to tens of degrees. Also, the phase pattern changes with variations in the parameters of the underlying ground surface. Both of these effects which reduces the accuracy of determining the coordinates of the consumer, and it is unacceptable to neglect their influence. To compensate the non-uniformity of the phase pattern, the calibration phase pattern of the transmitting antenna can be measured, which takes into account the presence of surrounding reradiators. Changes in the characteristics of the ground surface can be taken into account using an auxiliary small size calibration antenna, installed near the transmitting antenna.

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